NOLTR 66-21

DEVELOPMENT OF THE CONTINUOUS
WIRE METHOD. PROGRESS REPORT II.

NOL

17 MARCH 1966

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

20061031471

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DEVELOPMENT OF THE CONTINUOUS WIRE METHOD. PROGRESS REPORT II

By

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ABSTRACT: This report covers the second period of development work on use of the continuous wire method to follow shock-to-detonation transitions. It describes a successful method of producing satisfactory cast charges containing properly aligned wires. Methods of data reduction which have been developed are reported; they include as much automation as possible and have greatly reduced the data handling time. Detonation velocity measurements by the wire method on charges 15 cm long are accurate to within 0.5% (six shots). Values for cast Comp B and DINA are 7.97 and 7.72 mm/μsec, respectively. The first objective of future work is improvement of synchronization in the electronic circuits.

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NOLTR 66-21   17 March 1966

    The work reported here was carried out under two tasks,
R360 FR 105/R 011 01 01 Prob 059, Transition from Deflagration
to Detonation and RMMP 22 149 F 009 06 11 Prob 000, Propellant
and Ingredient Sensitivity. This report is the second on the
development work necessary to use the continuous wire method
in studies of the shock-to-detonation transition of high
explosives. The initial work was presented in NOLTR 63-136.

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DEVELOPMENT OF THE CONTINUOUS WIRE METHOD. PROGRESS REPORT II

INTRODUCTION

A previous report[1] detailed the initial progress in using a continuous resistance wire along the longitudinal axis of a cast charge to follow the shock-to-detonation transition. Briefly, the potential drop across a wire of known specific resistance (e.g., nichrome) in a constant current (0.200 amp) circuit is monitored as a function of time by an oscilloscope. As the detonation reaction sweeps down the charge, the length and corresponding resistance of the wire remaining in the circuit decreases. From the oscilloscope record, the position of the detonation front as a function of time can be obtained.

At the time of the first report, a satisfactory method of aligning the wires in a cast charge had been found, but not an acceptable method of producing good cast charges. A number of questions of reproducibility, precision, and interpretation of the records were raised. It is the purpose of this report to present information gathered in the second phase of developing this monitoring system.

After acceptable wired charges could be prepared (see below), work with the system was directed toward the following objectives:

1. Determine record reliability.

   (a) Compare record from resistance wire (generally nichrome)-Cu circuit with that from differential circuit (potential of nichrome-Cu minus that of Cu-Cu circuit).

   (b) Study synchronization of various circuits.

2. Interpret electronic records.

   (a) Which system gives more information?

   (b) Are results from different systems the same?

   (c) Do different systems measure the same phenomena?

3. Estimate reliability of the measurements.

   (a) Compare results with other methods of measurement.

(b) Precision and accuracy of measurements.

EXPERIMENTAL

Preparation of Charges

Satisfactory charges (no voids, particularly around the wires) of Comp B were finally prepared by casting at 84°C into a 2.5 in. diam mold (at 65°C) while holding the central wires under tension, as previously described[1]. A movable set of copper fingers through which steam (100°C) flows are kept in contact with the top bracket (to which the wires are attached) of each mold. The fingers are slowly raised as the solidification of the Comp B riser approaches and then covers the bracket. The process produced cast Comp B of 1.71 g/cc. Cast DINA was prepared in the same manner except that hot water (52°C) was circulated through the fingers, and the mold temperature was 30°C. The cast DINA so produced had a density of 1.60-1.64 g/cc.

The 3 wire charges are like those described in Ref. (1), and consist of a No. 32 (8 mil diam) Cu wire along the axis to serve as the ground. On either side, at 0.317 cm separation, is the second Cu wire and the AGW No. 40 nichrome wire (3 mil diam and resistance of about 2.3 ohms/cm). Charges prepared with coaxial wires* (a No. 40 nichrome wire insulated from and sheathed with a Cu tube of 18 mils O.D.) were made with the coax wire and a parallel Cu wire 0.317 cm distant placed symmetrically on either side of the charge's longitudinal axis. The Cu sheath of the coax served as the ground in this system.

Each finished charge was x-rayed. If wire alignment and charge continuity were acceptable, the charge was machined to its final dimensions of 3.81 cm diam by 15.25 cm. Of 20 charges requested, 3 were lost and 2 were rejected because of their poor quality as shown by the x-ray examination. This left eight charges with 3 wires (Cu, Cu ground, nichrome) and seven with a coaxial wire and parallel Cu wire. This number was insufficient for the study originally planned, but served to supply much of the information needed for further development.

Shot Design

All shots were made on unconfined charges; two standard tetryl pellets (5.08 cm diam x 2.54 cm long, ρ_o = 1.51 g/cc) were used as the booster. Attenuation of the tetryl shock was

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* Supplied by Precision Tube Co.

by a layer or gap of polymethyl methacrylate (PMMA) and cellulose acetate sheets. The calibration for this booster/gap system is available[2]. The three oscilloscopes were triggered by an ionization probe between the two tetryl pellets. The circuitry was much as in the initial work[1]; it will not be described here since it was revised because of the present results. The revised circuitry will be given in the next report.

Records

Data displayed on the oscilloscopes are the voltage vs time records; they are recorded as Polaroid transparencies. Figure 1 shows the three traces for the 3-wire shot No. 5 (130 card gap), and Fig. 2 analogous traces for Shot No. 15 (140 cards).

The Universal Telereader was used to reduce the data from these records. This machine provides a means of measuring distances on many types of paper and film records. An image of the record is magnified and projected on a view screen. Measuring cross-hairs are manually positioned along two orthogonal axes to the loci of points to be measured. The distances to these points, measured from an arbitrarily fixed reference point, are indicated in digital form on graduated dials incorporated into the unit.

By using an auxiliary unit, the Telecordex, the distances may be electronically indicated and automatically recorded (in this case on punched IBM cards). One revolution of the cross-wire drive shaft for either axis corresponds to approximately five inches of cross-wire travel and provides 2000 counts from a magnetic reading head. This equals approximately 0.0025 in. per count of cross-wire travel on the screen. Magnifying the image will correspondingly increase the number of counts per inch of travel and thereby allows a finer division of a given interval.

Besides the Universal Telereader, Telecordex, and card punch machine, the IBM 7090 high speed computer and the Cal-Comp automatic plotter were also used. The x vs y data from the Telereader was in the form of arbitrary divisions calibrated in the x-direction as time and in the y-direction as volts. These data (on punched cards) were then incorporated into an IBM 7090 computer program which converted arbitrary divisions to voltage, distance, or microseconds. The program also has an optional subroutine (least square fit to a straight line) which is used to calculate detonation velocities from the Nichrome and Differential distance vs time data. A Cal-Comp

subroutine then took the converted data and prepared a tape containing all the information necessary to make a finished voltage vs time or distance vs time plot, or both.

The tape is placed on the Cal-Comp plotter which automatically produces plots of voltage or distance versus time. The distance vs time graphs are plotted in two ways, unsmoothed points and least-square fitted points (for the linear portion). In order to compare the Nichrome, Copper, and Differential traces, a single plot allows one to determine whether or not the three traces are synchronous and also whether the subtraction of the reaction zone voltage, as indicated by the Copper record, from the Nichrome (which includes the voltage of the reaction zone) is equal to the voltage shown by the Differential.

Figs. 3 and 4 show the data, so reduced, from shots 5 and 15 respectively. They show that the records seem well synchronized for shot 5, but not for shot 15 which has about a 2 μsec difference between the straight line (detonation) portion of the Nichrome and Differential traces. Another shot (No. 11) showed a lack of synchronization of about 3 μsec in the opposite direction. Hence we cannot expect quantitative information from the present records except where the data can all be taken from a single trace or the record is of the steady-state detonation region where the relative differences are correct.

INTERPRETATION OF RECORDS

In the course of developing our present procedure of reducing the records, the Romco enlarger was compared with the Telereader. Also, for detonation velocity (D) determinations, the graphical procedure was compared with the analytical. The complete data (Appendix A) show that the Romco and Telereader were equivalent for reading the data; however, the Telereader is more convenient and has been adopted for the standard treatment. Graphical and analytical determinations of D also seemed equivalent, although the latter has been adopted as more convenient and preferable in principle.

Determination of Detonation Velocity

All shots were made in the configuration of the standardized gap test[3] with a tetryl booster 5.08 cm diam x 5.08 cm long and ρ_o = 1.51 g/cc. All shots were treated in the same manner in Table A1 to show the equivalence of different methods of determining the steady state velocity from the records. To determine the precision of the method, however, only shots with sufficient boostering to exhibit a negligible run-length to detonation were selected. Data for four such shots on Comp B

are given in Table 1. If the charges are considered equivalent, the six velocities measured give the values of 7.97 mm/μsec ± 0.6% (95% level). This compares well with the literature value of 7.94 mm/μsec[4]. Under the condition of strong boostering, the data of Table 1 show no significant difference between rates obtained from any of the three circuits. However, more data would surely show that the velocity obtained from the Nichrome record compressed into a 57 volt scale is less accurate than that from the Differential record with a 14 volt scale (See Figs. 1 and 2). The larger standard deviation found for the Nichrome results on all shots (See Appendix) also indicates this. Henceforth, velocities will be read only from the Differential records which offer the better space resolution.

Table 2 presents detonation velocity measurements made on cast DINA. It is 7.72 mm/μsec compared to the literature value of 7.77[*][6]. Here six charges give the average value to within ± 0.4% (95% level). With the one exception noted, all single shot values here were within ± two standard deviations (2σ) of the average value. This was also true of the Comp B data. We are just in the process of making simultaneous optical and continuous wire determinations on the same charge. However, optical and electronic results on charges from the same lot of material leave little doubt that the two methods are equivalent. Thus the same value has been obtained in each case for tetryl (7.17 mm/μsec)[6] and for a PBXW composition (6.10 to 6.13 mm/μsec)[7].

Although the Differential, Nichrome, and Coax appear to give the same value of the detonation velocity on the well boostered charges they differ in the measured velocity after transition in the more critically boostered charges. The Nichrome value is higher, the Coax value lower than the Differential. (See Appendix.) Since the Differential should permit more accurate distance measurement and measures a D closest to that of Table 1, its value will be used. The steady state velocity after transition would be expected to be the same in every case although under-or over-boostered rates are always possible. At this point in the transitional study, it is sufficient to show that detonation has been achieved. Measuring the rate to within 5% is quite adequate to do this.

Run-Length and Delay Time to Detonation

For study of the shock-to-detonation transition, we wish information about reactivity (as indicated by conductivity) in

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* Value quoted is for cast DINA, ρ_0 = 1.60 g/cc, in charges of 22 mm diam. Both α and β crystal forms exhibit the same velocity. See also value of 7.80 mm/μsec for charge of ρ_0 = 1.64 (probably a pressed charge) quoted by Dremin and Shvedov in Zh Prikl Mekh Tekhn Fiz No. 2, 154-159 (1964).

the transitional region as well as a measure of the familiar delay time τ and run length X_ℓ observed for such transitions. It is evident that if we wish to take advantage simultaneously of the better space resolution of the differential record, of the negligible resistance of the Cu wire which permits measuring the resistance of the reacting front in the Cu-Cu circuit, and of the location and conductivity of the front given by the nichrome-Cu circuit, the three oscilloscopes must be triggered simultaneously and be very well synchronized. It is also evident, as has already been remarked above, that this was not the case in several of our records. Revised and improved circuitry to achieve adequate synchronization is therefore the first requirement for future development.

If the response time of the circuit is adequate, delay time to detonation can be obtained from t_o, the time at which detonation begins, because

$$\tau = t_o - 3.5 \, \mu sec^* - (\text{shock transit time through gap}),$$

and the transit time through the gap is known from calibration data[2]. Once t_o is known, the resistance at that time can be read from the differential plot and the corresponding distance X_ℓ determined.

Detonating Comp B has a resistivity of 0.1 ohm-cm[8]. On our scale the detonating front would appear to have zero resistance. It seems reasonable to assume that the point of zero resistance on the Cu-Cu trace (Figs. 5 and 6 for shots 5 and 15, respectively) could be taken as the beginning of detonation. As the figures show, this is not a sharp change** in Comp B which exhibits some conductivity for periods as long as

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* Time for detonation to travel from triggering probe through 2.54 cm of tetryl $\rho_o = 1.51$ g/cc.

** Figs. 5 and 6 also demonstrate the continued conductivity beyond the end of the charge. This is caused, on all records, by the continued presence of conductive detonation products; radial probes within a detonating charge indicate conductivity for period of 4 μsec. We have been unable to eliminate this extension of the records although several insulations have been tried. It makes determining the time at which detonation ends more difficult. This time, however, has little value for transitional studies. It is used only to check record synchronization or the consistency of velocity data.

10 μsec before zero resistance is reached. Other explosives (e.g., DINA) exhibit practically none of this transitional behavior. The value t_o obtained from the Cu-Cu traces will be designated $t_o(Cu)$; it is easily read reproducibly.

Another point which might equally reasonably be considered the start of detonation is the earliest value on the straight-line (detonation) portion of the differential trace. This value, $t_o(d)$, is generally very difficult to select and to read reproducibly.

Table 3 contains the two sets of data selected in this manner. Unfortunately, they are two distinct sets with the τ X_ℓ values derived from $t_o(Cu)$ generally smaller than those from $t_o(d)$. The expected trend of increasing τ and X_ℓ with decreasing shock strength is evident only in charges 5 and 6 for which record synchronization appeared good (e.g., Fig. 3).

Some selection between these sets might be made on the basis of the ratio X_ℓ/τ, the average velocity of the shock from its point of entry to the point of initiation of detonation. This must be supersonic; indeed, in the wedge work[9] the shock travels most of X_ℓ at its entering velocity and then accelerates rapidly to D. The average velocity should therefore be not only supersonic but higher than the initial shock velocity. From a combination of calibration and Hugoniot data, the initial shock velocity in the acceptor $(U_{H.E.})$ has been computed and is shown in Table 4. The run-length to be expected is then at least $(U_{H.E.}\tau)$. Table 4 seems to show rather better agreement between this prediction and the X_ℓ measured for the set of values derived from $t_o(d)$ than with those from $t_o(Cu)$. Work which has since been done on DINA covered a greater range of pressures and indicated that in the higher pressure range, as contrasted to the region studied here very near the 50% point, values derived from $t_o(Cu)$ are more valid. Obviously a greater range in shock pressures should be investigated, and well synchronized electronic records should be compared with optical records obtained at the same time.

Coaxial Wire Records

The coax wire seems a poor design for transitional measurements. The data obtained with it are presented to discourage its use for this purpose.

Any use of the coax immediately raises the question of whether it will respond to shock pressure alone. To answer this

question, a five inch length of coax was mounted in wax and in water. The inert material was shocked with the standard tetryl donor. The exposed end of the wire was shorted and a constant resistance (corresponding to the entire length of wire) was recorded for 6-10 μsec; the voltage then fell to the imposed circuit voltage. This particular coax wire does not respond to this strength shock in an inert.

Table 5 contains τ(Cu) and τ(d) data compiled from the coax shots. The τ(d) values are compared with those from the three wire shots as a function of attenuator thickness in Fig. 7. (Since all shots were near the 50% point, the number of cards is a far more sensitive variable than shock pressure at the end of the gap.) The figure shows that for the same initial shock, the coax wire indicates transition to detonation 1.5 to 6 μsec later than does the 3 wire system. The most direct explanation is that as initiation conditions become more marginal, the coax responds increasingly sluggishly. Hence although it can be used to obtain a good measure of the detonation velocity in a well boostered common H.E., it is unsuited for studying the shock-to-detonation transitional region.

The Transitional Region

The successful use of the continuous wire method to measure detonation velocities supports the validity of our assumption that a very thin detonation front closes the nichrome-copper circuit during detonation of a conventional explosive. Even in this case, we have shown the response of the coax system to be inadequate, under marginal boostering, to establish the exact location and time at which detonation begins. The question of the validity of such measurements with the three wire system has still to be resolved by future work.

In the transitional region, that area between the first evidence of pre-detonative reaction (detectable conductivity) and full detonation, the assumption of a thin conducting front cannot be made. It is most probable that a fairly thick layer of partially reacted (conducting) explosive will produce an integrated resistance measurement over a finite length of the circuit. This condition might last until detonation develops or the length of the conducting zone might decrease continuously as detonation is approached.

Let us consider just the Cu-Cu circuit during detonation. Figure 8 shows a section of this circuit for which the measured resistance will be that of the partially reacted explosive bounded by the two wires. If we make a gross approximation to this system with a rectangular volume of explosive of 0.0203 cm

(wire diam) x 0.317 cm (wire separation) x X(thickness of conducting layer), then the resistance will be

$$R = r \; \ell/A$$

where

R is **resistance in ohms**
r is resistivity in ohm-cm
ℓ is length of volume unit parallel to the current flow = 0.317 cm
A is area perpendicular to the current flow = 0.203 X cm^2.

The dimensions used give

$$R = 15.6 \; r/X$$

and for Comp B with r = 0.1 ohm-cm[8],

$$X = 1.56/R \text{ cm.}$$

Thus to obtain a resistance as low as one ohm, this model requires a 15.6 mm layer of the highly conducting material. Because the approximation is a very rough one, the actual length of wire that must be shorted out by the detonation front (or the detonation products behind it) is probably much smaller. We believe it to be at least an order of magnitude smaller. But the model is used to show that even the highly conductive detonation front must have a finite thickness to produce the negligible resistance measured by the Cu-Cu circuit. It follows that reactions short of detonation producing resistivities higher than 0.1 ohm-cm will require greater thicknesses of conducting material. Probably the effective value of X decreases continuously over the transitional region to assume its lowest value when detonation begins. It is planned to supplement the continuous wire measurements in the transitional region by radial measurements of resistance vs time at fixed locations.

It was reported in Ref. 1 that several Cu-Cu records appeared to show a linear log conductance vs time curve in the transitional region. This has not been confirmed by the better data of the present work. Table 6 contains the data from three shots and Fig. 9 displays the sigmoid curves obtained.

Other Information

Three additional experimental charges were prepared; each contained three wires in the usual positions. In this set of charges, the resistance wire was Moleculoy instead of nichrome.

Moleculoy is an alloy (chiefly nickel and chromium) of higher tensile strength, lower thermal expansion and lower temperature coefficient of resistance than nichrome. Moreover its resistance is 3.65 ohms/cm, about 60% greater than that of the nichrome.

Good electronic records were obtained from these three shots. They were quite as good and possibly better than the average record produced by the three wire-nichrome system. Consequently Moleculoy will be used as the resistance wire in all future work.

SUMMARY

During this phase of the reported work, a method of obtaining satisfactory cast charges containing well aligned resistance and copper wires was developed. It depends chiefly on the use of steam or hot water fingers in contact with the mold brackets used to hold the wires under tension during casting of the charge.

A number of automatic procedures for reading the records and reducing the data from them have been developed. Their use has improved the precision of the data obtained and has greatly shortened the time necessary for data reduction.

Detonation velocity measurements made on charges of Comp B and DINA 3.81 cm diam. x 15.25 cm showed a 95% confidence level spread of 0.5% (6 shots). Single shots were, with one exception, within 1% of the mean value. Average values are 7.97 and 7.72 mm/μsec for cast Comp B and DINA, respectively. Continuous wire values obtained for the detonation velocity of tetryl and a PBXW were the same as those obtained optically on other charges made from the same materials.

Although either the 3 wire system or the coaxial wire system can be used equally well to measure the detonation velocity of well boostered explosives, the coax system lags behind the single wire system in its response when the boostering approaches critical strength. This behavior, as well as the lack of explosive between the resistance wire (core) and ground (sheath), makes the coax system quite inadequate for transitional studies.

The obvious deficiency of the present experimental conditions is the demonstrated lack of synchronization between the three simultaneously recorded records. The first objective of future work is consequently the improvement of the electronic circuitry. When this is accomplished, both optical and electronic monitoring will be used on unconfined charges. The optical results should confirm the establishment of synchronization as well as assist in a more quantitative interpretation of the records (delay time, run-length, and transitional behavior) than can now be made.

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TABLE 1

Detonation Velocity of Cast Comp B

Shot No.	Record	Gap No. Cards	Detonation Velocity m/sec
1	Differential	0	7944
1	Nichrome	0	8059
2	Differential	65	7964
2	Nichrome	65	7999
3	Coax	65	7864
4	Coax	0	7964

Av. 7966 (σ = 42.3)

D = 7966 $\pm$ 49 m/sec at 95% confidence level

Charge density 1.71 g/cc

Charge dimensions 1.81 cm diam x 15.24 cm long, unconfined

50% point ca 142 cards

TABLE 2

Detonation Velocity of Cast DINA

Shot No.	Confinement	Gap No. Cards	Detonation Velocity m/sec
1	No	0	7730
2	No	0	7690
5	No	0	7690
12	No	140	7740
15	Yes	0	7750
16	Yes	0	7550*
24	Yes	140	7700

Av 7717 (σ = 24.3)

D = 7717 ± 28 m/sec at 95% confidence level

Charge density	1.60 ± 0.02 g/cc
Charge dimensions	3.81 cm diam x 15.24 cm long
Confinement	Steel tube 3.81 cm I.D., 4.03 cm O.D.
DINA	Lot X249
50% Point	226 cards (unconfined) and 279 cards (confined)

* Omitted from average because deviation was about 7 σ.

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Table 3

Data for Unconfined Comp B from Three Wire Charges

Shot No.	Gap No.Cards	Gap mm	Time Shock Enters Acceptor[a] μsec	$t_o(Cu)$[b] μsec	Delay Time[c] $\tau(Cu)$ mm	Run Length[d] $X(Cu)$ mm	$t_o(d)$[b] μsec	$\tau(d)$[c] μsec	$X(d)$[d] mm	Comment
1	0	0	3.5	4.5	0.7	-0.6	4.3	0.8	-	Rise time 0.3 μsec
2	65	16.5	6.8	7.8	0.7	-1.6	8.3	1.5	-	Rise time 0.6 μsec
5	130	33.0	10.7	18.4	7.4	21.8	20.8	9.8	37.4	
6	134	34.0	11.0	20.9	9.6	34.4	24.4	13.1	47.0	
11	135	34.3	11.1	24.4	13.0	45.8	24.3	12.9	43.0	Records not synchronized
14	138	35.0	11.3	19.6	8.0	1.1	21.8	10.2	44.4	Records probably not synchronized
15	140	35.6	11.4	22.8	11.0	38.2	24.8	13.1	48.4	Records not synchronized

a. Time for detonation of tetryl pellet (3.5 μsec) plus transit time through gap known from calibration/2.

b. $t_o(Cu)$ is time Cu-Cu circuit reaches zero resistance; $t_o(d)$ is first point on straight line portion of differential curve and is very difficult to select.

c. $\tau(Cu) = t_o(Cu)$ - time shock enters acceptor - 0.3 (rise time).
    $\tau(d) = t_o(d)$ - time shock enters acceptor -0.3 (rise time).

d. $X(Cu)$ is 15.24 cm minus length of wire left according to resistance shown on differential record at $t_o(Cu)$. $X(d)$ is analogous value read from differential at $t_o(d)$.

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Table 4

Test of Data for Consistency

Shot No.	Gap No. Cards	Gap Pressure[a] kbar	$U_{H.E.}$ Shock Vel.[b] in H.E. mm/μsec	$U_{H.E.}$ τ(Cu) mm	X_ℓ(Cu) mm	$U_{H.E.}$ τ(d) mm	X_ℓ(d) mm	
5	130	38.3	3.99	29.6	21.8	39.1	37.4	
6	134	37.0	3.97	38.2	34.4	52.0	47.0	
11	135	36.5	3.93	51.1	45.8	50.7	43.0	} Records not synchronized
14	138	35.7	3.91	31.3	-	39.9	44.4	
15	140	34.6	3.88[c]	42.7[d]	38.2	50.8	48.4[d]	

a. From gap test calibration /2

b. From Hugoniot for Comp B /10

c. Surface shock velocity of 3.74 mm/μsec measured optically on this charge

d. Run-length of 45.1 mm measured optically

Table 5

Data from Coaxial Wire in Comp B

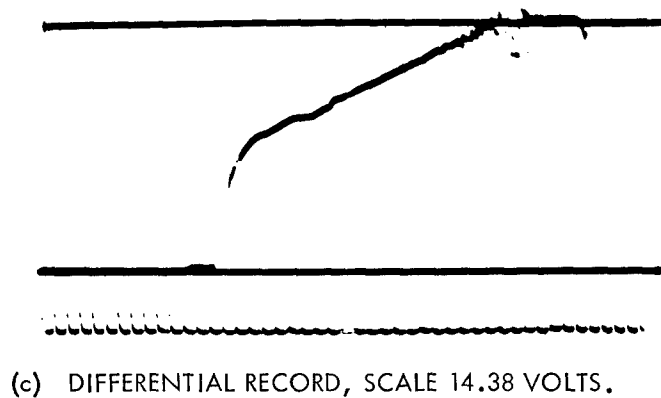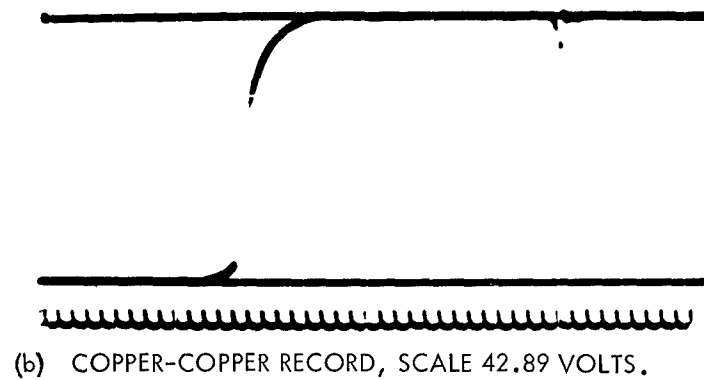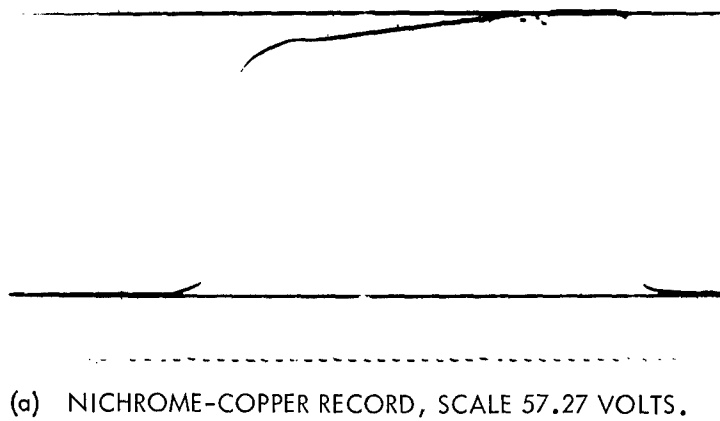| Shot No.	Gap No. Cards	Gap mm	Time Shock Enters Acceptor* μsec	$t_o*(Cu)$	$\tau(Cu)$**	$t_o(d)$*	$\tau(d)$**	Comment
4	0	0	3.5	4.2	0.7			Rise time of 0.5 μsec
3	65	16.5	6.8	-	-			Cu-Cu record lost
7	130	33.0	10.7	23.3	12.1	22.8	11.6	
8	134	34.0	11.0	24.5	13.0	24.5	13.0	
10	135	34.3	11.1	29.3	17.7	28.0	16.4	See note below
12	136	34.6	11.2	27.7	16.0	26.4	14.7	
13	138	35.0	11.4	30.6	18.7	29.8	17.9	

* Defined as in footnote of Table 3

** Defined as in footnote of Table 3 except that delay time of 0.5 μsec used

Note: On shot No. 10, nichrome wire showed short at the shocked surface, and registered resistance of entire length (15.24 mm) for 13 μsec before indicating detonation.

Table 6

Data from Cu-Cu Records: Resistance vs Time Measured In Shocked Comp B

Shot 5

Resistance (ohms)	187	126	93.0	67.5	46.0	28.5	17.5	9	5	0
Conductivity (mhos)	0.005	0.008	0.011	0.015	0.022	0.035	0.057	0.111	0.20	∞
Time (μsec)	13.3	13.7	13.9	14.4	14.7	15.3	16.0	17.1	17.8	18.4

Shot 6

Resistance (ohms)	136.5	99.0	74.0	52.0	39.5	32.0	26.5	19.5	13.0	7.0	0.5
Conductivity (mhos)	0.007	0.0100	0.0135	0.0192	0.0253	0.0312	0.0377	0.0513	0.0769	0.143	2.0
Time (μsec)	14.5	14.8	15.3	15.9	16.6	17.2	17.9	18.8	19.5	20.3	20.9

Shot 15

Resistance (ohms)	199	168	134.5	107	74.5	50.0	36.5	26.0	18.5	10.0	3.5	0
Conductivity (mhos)	0.005	0.006	0.0074	0.0093	0.0134	0.020	0.027	0.038	0.054	0.100	0.286	∞
Time (μsec)	14.4	14.7	15.0	15.4	16.0	16.8	17.7	18.6	19.6	20.9	21.8	22.7

(a) NICHROME-COPPER RECORD, SCALE 57.27 VOLTS.

(b) COPPER-COPPER RECORD, SCALE 42.89 VOLTS.

(c) DIFFERENTIAL RECORD, SCALE 14.38 VOLTS.

NOTE: THE ABSCISSA IS TIME IN μ SEC AND INCREASES TO THE RIGHT

FIG.1   THREE VOLTAGE-TIME RECORDS FOR SHOT 5 ON CAST COMP B
WITH 130 CARD GAP
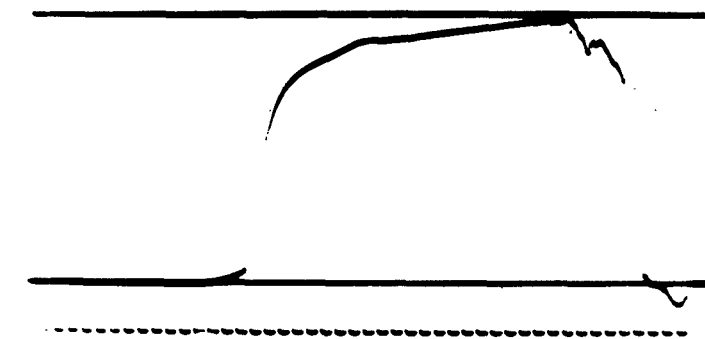
(a) NICHROME-COPPER RECORD, SCALE 57.36 VOLTS.

(b) COPPER-COPPER RECORD, SCALE 42.98 VOLTS.
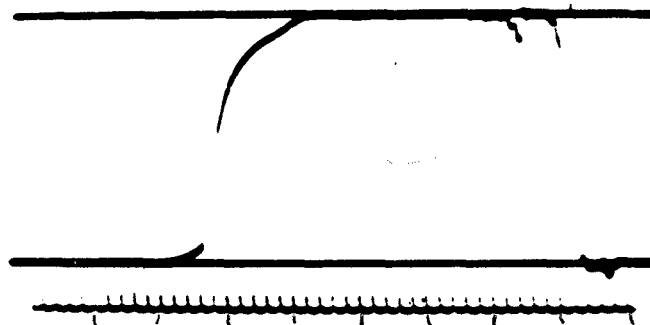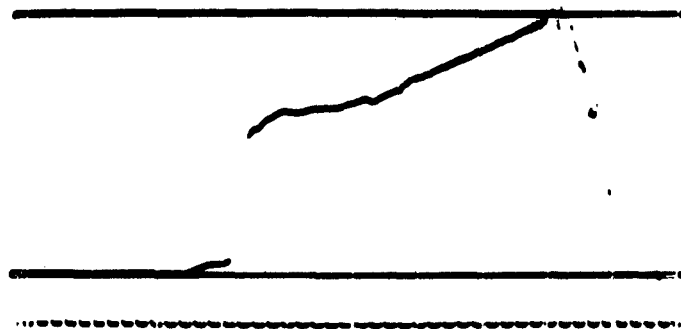
(c) DIFFERENTIAL RECORD, SCALE 14.38 VOLTS.

NOTE: THE ABSCISSA IS TIME IN μ SEC AND INCREASES TO THE RIGHT

FIG.2 THREE VOLTAGE-TIME RECORDS FOR SHOT 15 ON CAST COMP B
WITH 140 CARD GAP
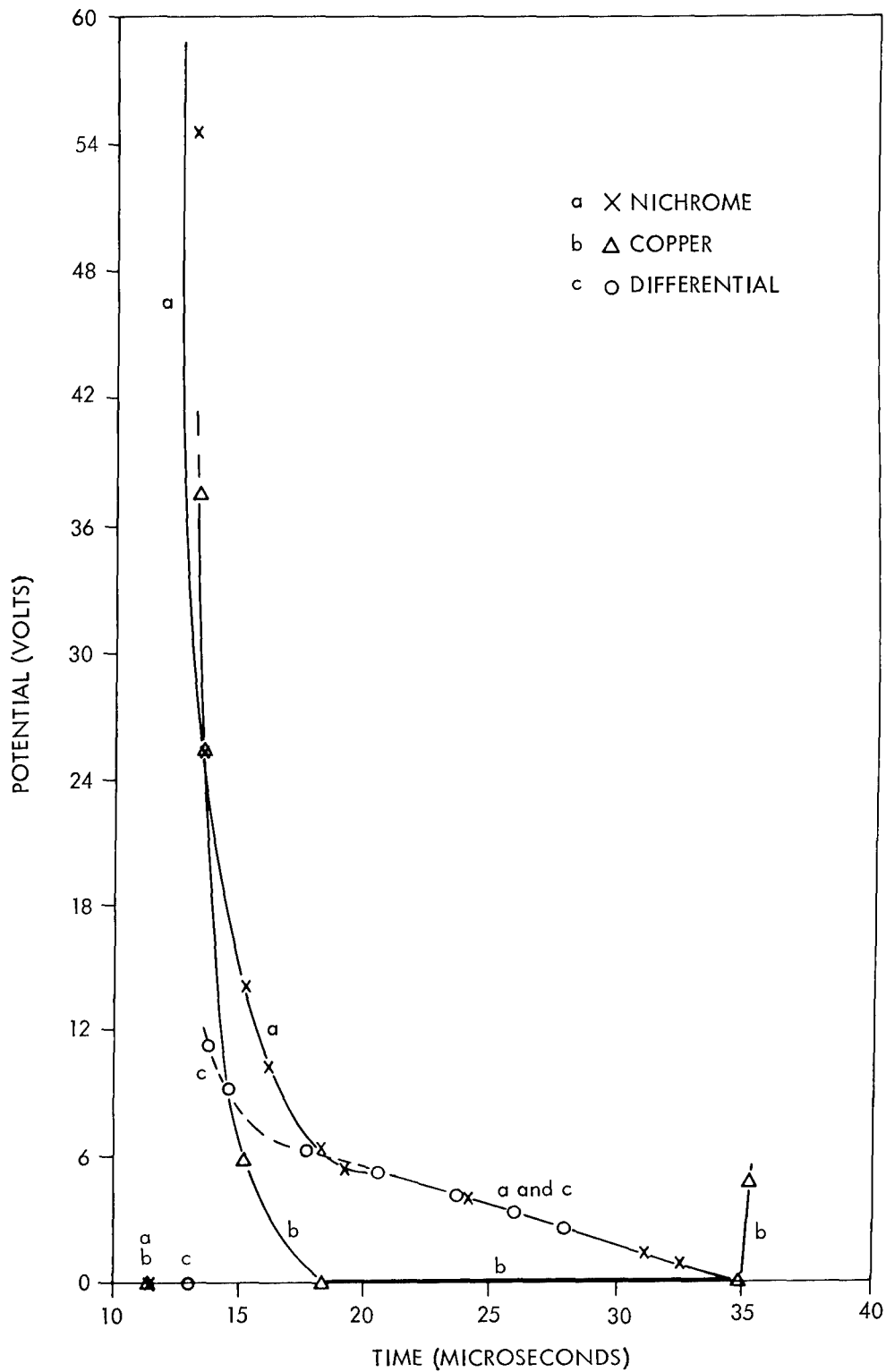
FIG. 3 TELEREADER TRACES OF THREE RECORDS SHOWN IN FIG. 1
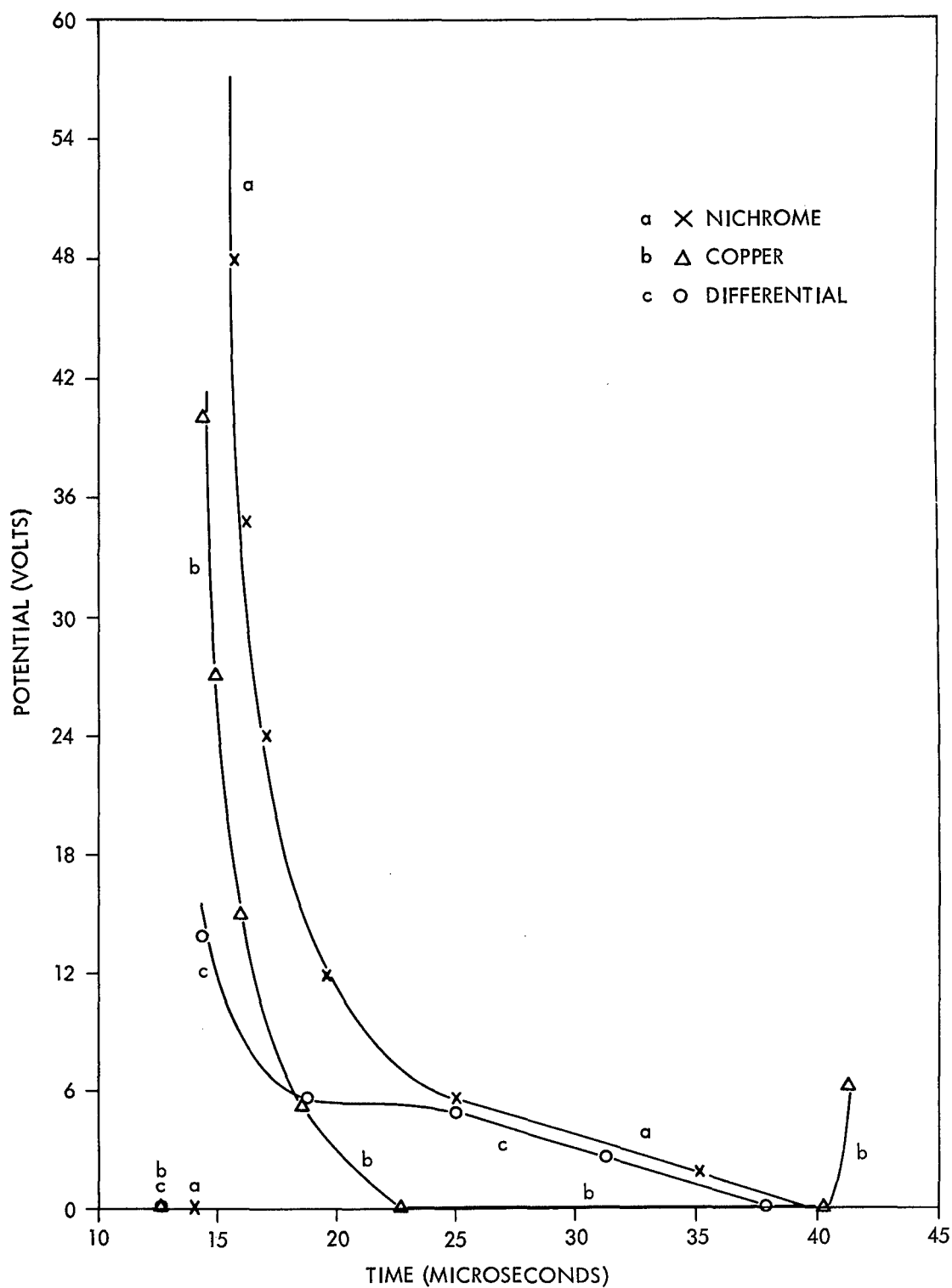
FIG. 4 TELEREADER TRACES OF THREE RECORDS SHOWN IN FIG. 2
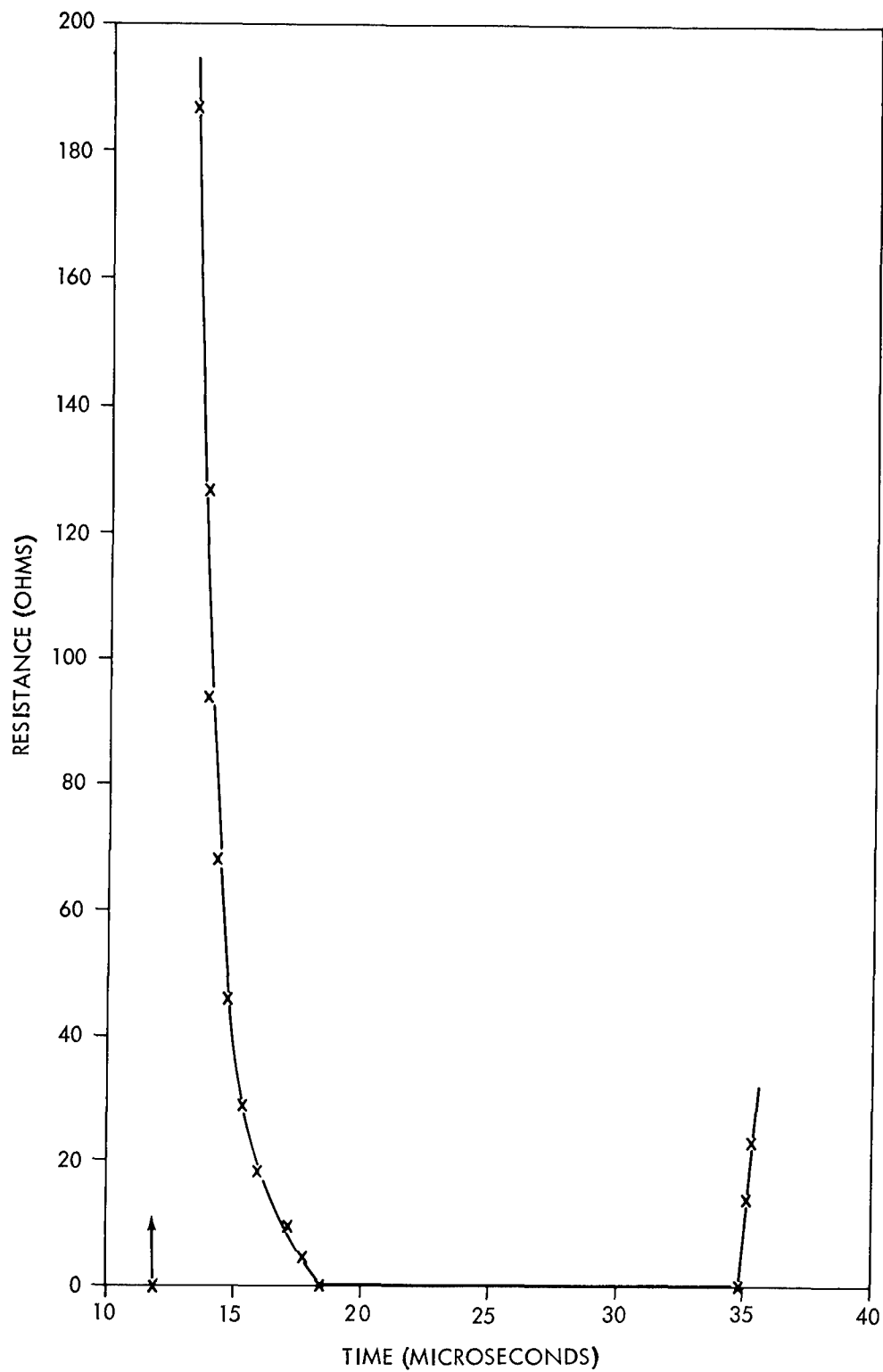
FIG. 5 TELEREADER TRACE OF RECORD SHOWN IN FIG. 1b COPPER RECORD FOR SHOT 5
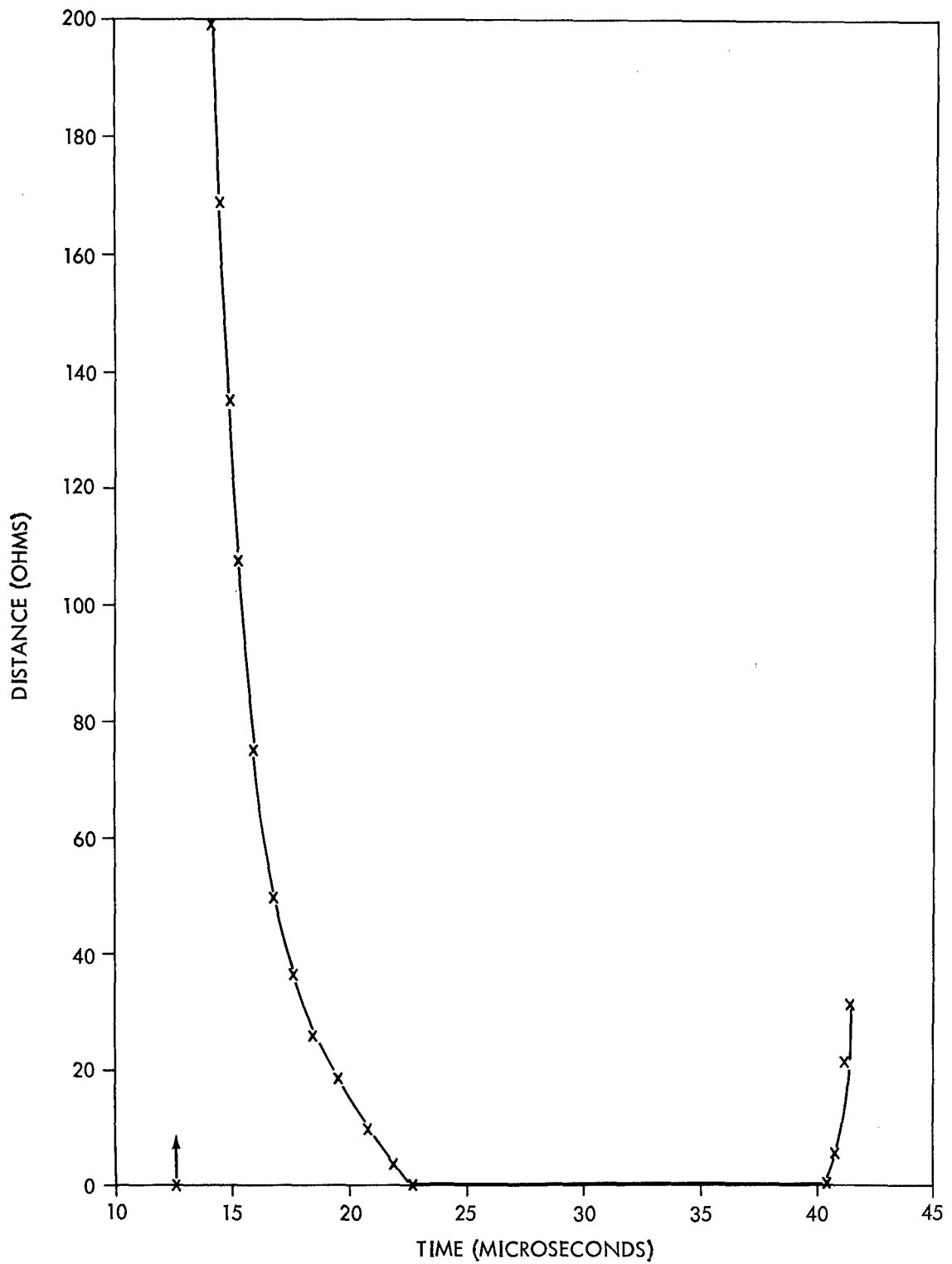
FIG. 6 TELEREADER TRACE OF RECORD SHOWN IN FIG. 2b COPPER RECORD FOR SHOT 15

FIG.7   RESPONSE TIMES FROM DIFFERENTIAL RECORDS AS FUNCTION
OF GAP THICKNESS

TWO PARALLEL COPPER WIRES
OF 0.0203 CM DIAM. WITH
LONGITUDINAL AXES 0.317
CM APART
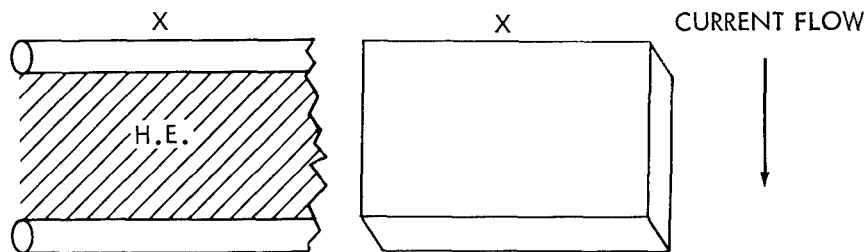
FIG.8   MODEL FOR SECTION OF Cu-Cu CIRCUIT
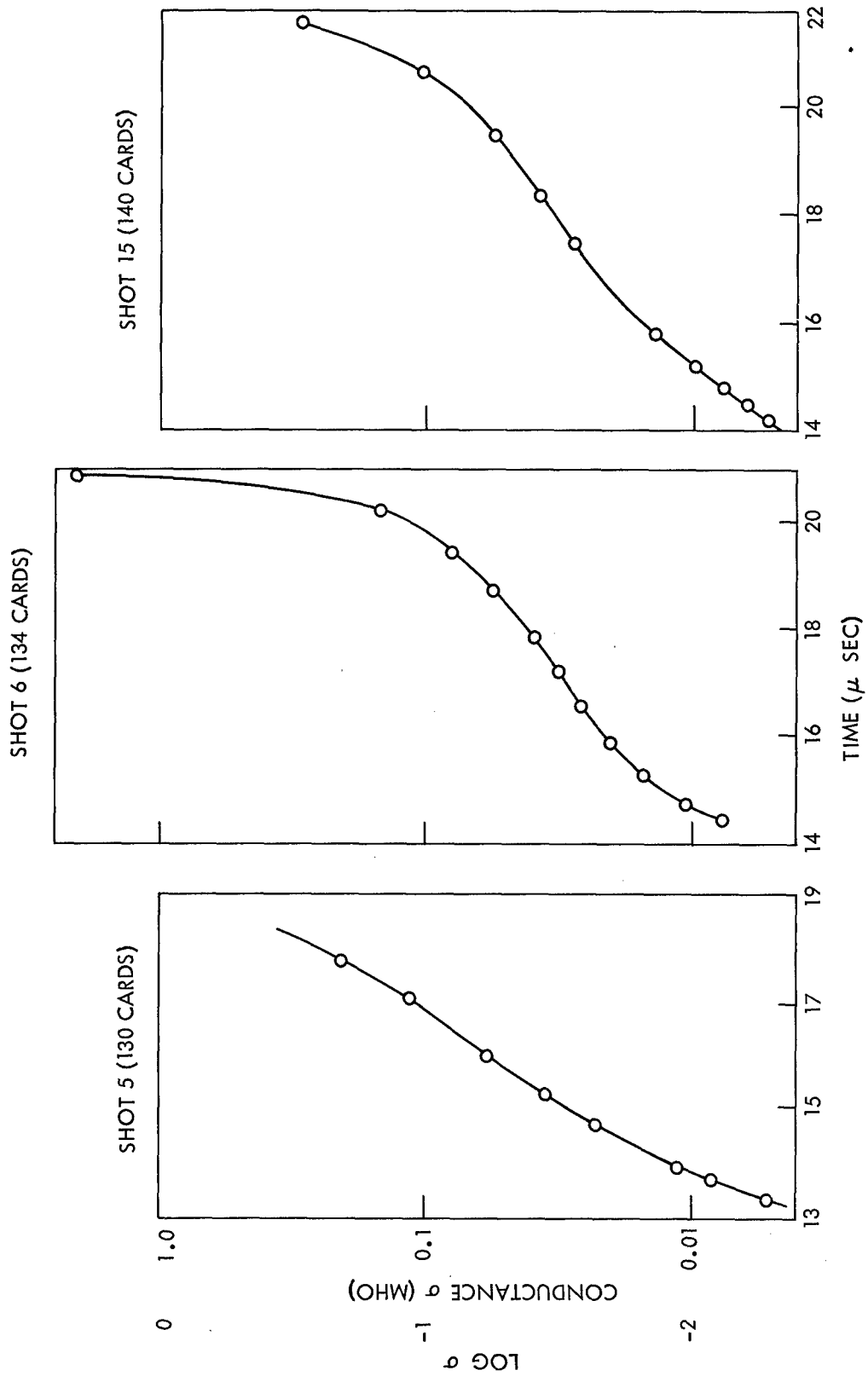
FIG.9 VARIATION OF CONDUCTANCE WITH TIME (Cu–Cu RECORD FOR COMP B)

Appendix: Detailed Velocity Measurements on Comp B

Table A 1

Detonation Velocity of Cast Comp B

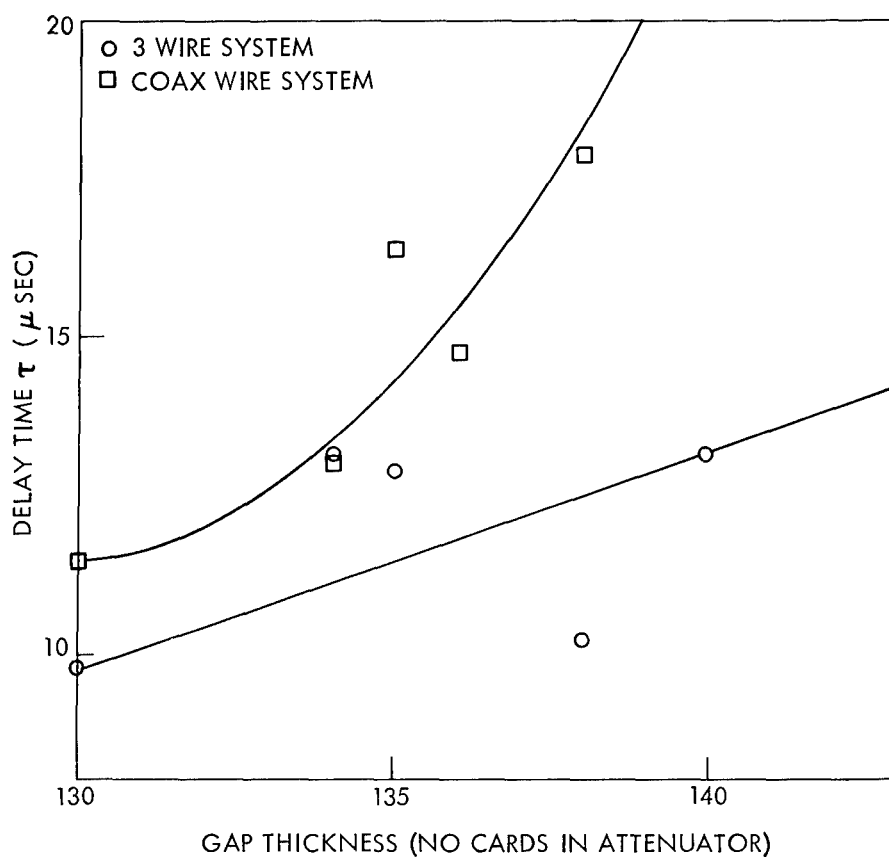| Shot No.	Gap No. Cards	Differential Record			Nichrome Record		
		Telereader Analyt.	Graph.	Rumco Graph.	Telereader Analyt.	Graph.	Rumco Graph.
1	0	7944	7871	7976	8059	8114	8025
2	65	7964	7866	8086	7999	7866	7972
5	130	8013	8200	7953	8352	8239	8380
6	134	8025	8106	8120	8243	8188	8699
11	135	8137	8134	8184	8723	8635	8920
14	138	8244	8270	8050	8462	8573	8774
15	140	7845	7839	7930	8467	8528	8371
16*	142	7843	7873	7926	8340	8390	8317
Average		8002	8020	8028	8331	8328	8432
Standard Deviation %		1.6	1.9	1.1	2.6	3.0	3.2

Coaxial Wire

Shot No.	Gap No. Cards	Telereader Analyt.	Graph.	Rumco Graph.
4	0	7964	7927	7875
3	65	7864	7788	7834
7	130	7810	7846	7903
8	134	7856	7867	7775
10	135	7649	7650	8006
12	136	7764	7798	7723
13	138	7512	7600	7445
Average		7817	7782	7794
Standard Deviation %		1.9	1.4	2.1

* Inferior charge by x-ray examination which revealed pores

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

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5. AUTHOR(S) *(Last name, first name, initial)*

Price, Donna
Jaffe, Irving
Toscano, John P.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
17 March 1966	27	10

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
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This report describes successful methods of producing cast charges containing continuous wires and of semi-automatic data reduction of the electronic records obtained. Detonation velocity measurements were accurate to $\pm 0.5\%$. Future development work on the continuous wire method will emphasize synchronization of records.

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Detonation Velocity Measurement						
Shock to Detonation Transition						
Comp B						
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